GPS Constraints on Present-Day Strain in the U.S. Midcontinent

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Non-Technical Summary

Observations from a new high-precision GPS geodetic network in the southern Illinois Basin provide evidence for present-day tectonic strain in the Wabash Valley seismic zone, an area associated with a concentration of historical and instrumentally recorded earthquakes, paleoseismic evidence of repeated, large-magnitude earthquakes, and possible Quaternary faulting. The GPS network consists of 56 sites distributed over a 100,000 km^2 area of Illinois, Indiana, and Kentucky, augmented by a dense 24-station geodetic array in the Shawnee National Forest of southernmost Illinois. The results reported here are based on a five GPS campaigns, conducted from 1997-2003, and suggest statistically significant horizontal motions at 28 of the sites surrounding the Wabash Valley seismic zone. The inferred velocities are highly variable, presumably influenced by systematic and random geodetic errors, as well as significant non-tectonic deformation sources, such as mine- and solution-related subsidence. Nonetheless, the individual site velocities, as well as a formal inversion for tectonic strain, suggest a systematic pattern of shear strain that may be interpreted either as sinistral shear along the NNE-trending Wabash Valley Fault System or as dextral shear along the NE-trending Commerce Geophysical Lineament. The shear strain rate estimated for the area surrounding the Wabash Valley Fault System is estimated at $2.3 \pm 0.8 \times 10^{-9}$ yr^{-1}, in a similar direction, but at a significantly smaller magnitude than previously measured rates in the New Madrid seismic zone.

Investigations Undertaken

The work is centered on observations from a new high-precision GPS geodetic network in the southern Illinois Basin. These observations provide evidence for present-day tectonic strain in the Wabash Valley seismic zone, an area associated with a concentration of historical and instrumentally recorded earthquakes, paleoseismic evidence of repeated, large-magnitude earthquakes, and possible Quaternary faulting. The GPS network consists of 56 sites distributed over a 100,000 km^2 area of Illinois, Indiana, and Kentucky. Through additional support from NSF, we were able to extend those observations through field measurement campaigns in 2000, 2002, and 2003. Measurements made in 2000 and 2003 include observations at a dense geodetic array in the Shawnee National Forest of southernmost Illinois, in the Hicks Dome/Fluorspar area. These measurements extend the observations through six years and provide additional observational constraints on present-day deformation in the U.S. midcontinent.

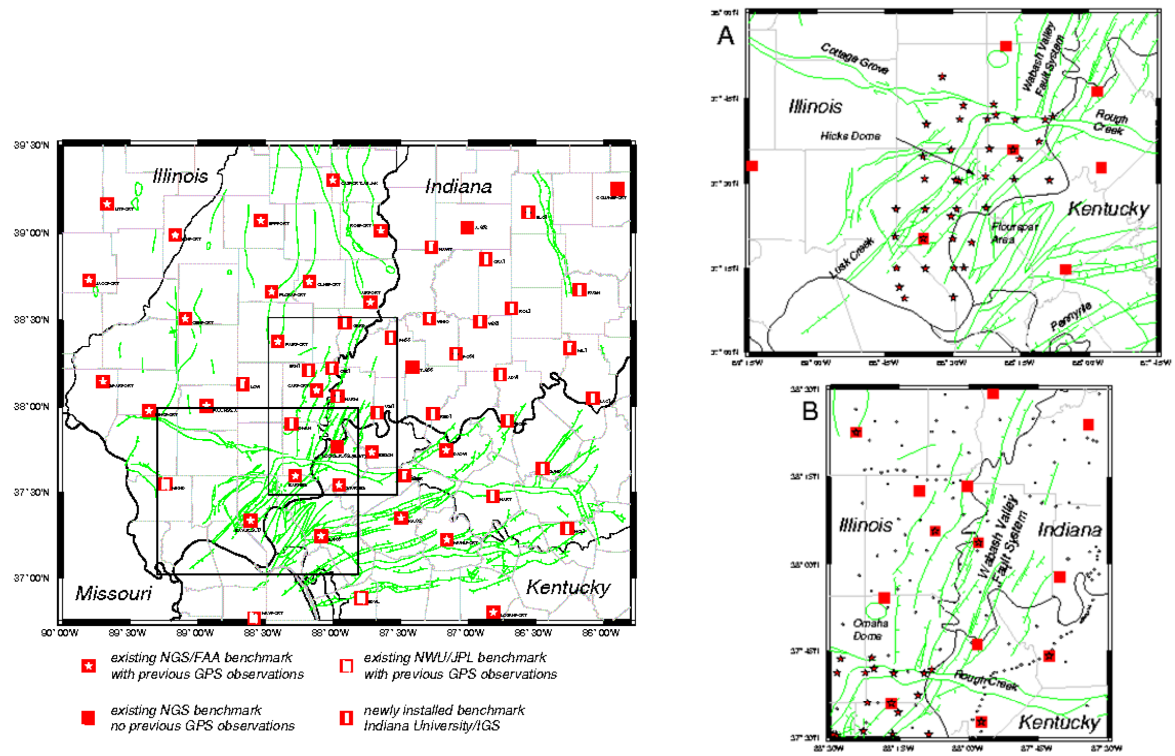

Figure 1. *(Left) Southern Illinois Basin geodetic network. Large symbols show benchmarks observed during the 1997-2002 GPS campaigns. Structural features from Bear et al. [1997]. Rectangles show areas of possible densification in the maps shown at right. (Right) Areas of proposed densification of the regional GPS network: (A) Hicks Dome/Fluorspar district of southern Illinois; (B) Wabash Valley area of southern Indiana/Illinois. Squares indicate locations of stations in our regional GPS network; stars indicate sites with previous GPS observations; small diamonds indicate first-order triangulation or leveling sites.*

This project seeks to assess present-day deformation of the Wabash Valley seismic zone using high-precision geodetic measurements using the Global Positioning System (GPS). In the past several years, a number of groups have initiated GPS geodetic measurements in the central U.S. These measurements have focused primarily on the New Madrid seismic zone [Liu et al., 1992; Snay et al., 1994; Weber et al., 1997; Newman et al., 1999]. Because the existing GPS networks in the Central U.S. extend only to the very southern edge of the Illinois Basin, our project has succeeded in extending this network to the northeast to envelop the Wabash Valley seismic zone [Hamburger et al., 2002].

Results

In this grant period, we have focused on analysis of existing GPS measurements at a new geodetic network surrounding the Wabash Valley seismic zone. The GPS network, shown in Figure 1, consists of 56 geodetic sites extending over an area of 100,000 km^2 in southern Indiana (20 sites), southern Illinois (23 sites), and western Kentucky (13 sites). The network includes 28 existing geodetic sites that are part of the National Geodetic Survey (NGS) network of first-order triangulation and/or leveling benchmarks. Campaign measurements were made in the summers of 1997, 1998, 2000, 2002, and 2003.

The full data set from the field campaigns has been transferred to the UNAVCO data archive, where they will be made available for use by other researchers working in the area. The GPS data were analyzed using the GIPSY/OASIS II software [Zumberge et al., 1997]. Raw GPS data collected in the field were analyzed in 24-hour daily solutions along with regional and well-distributed globalcontinuous sites. We used fixed orbits obtained from JPL's submission to the IGS. Each daily solution was then transformed into the ITRF97 reference frame. Finally, the individual daily GPS solutions in the ITRF97 reference frame were combined together to determine site positions at epoch 1998.0 and site velocities. For more details aout the strategy, refer to Larson et al. [1997] and Freymueller et al. [1999, 2000]. In this survey, we used a 'local' frame of reference, fixed with respect to our base station BLO1, which is presumed, based on the distribution of seismicity, to lie outside the most actively deforming area. Formal errors in coordinates and velocities were estimated from the coordinate covariance matrices. Because these formal errors frequently under-represent the true observational errors [e.g., Larson and Agnew, 1991], they were then scaled to match the 95th percentile (χ^2) of the repeatability of the daily site coordinate estimates. Estimated site velocities are shown in Fig. 2.

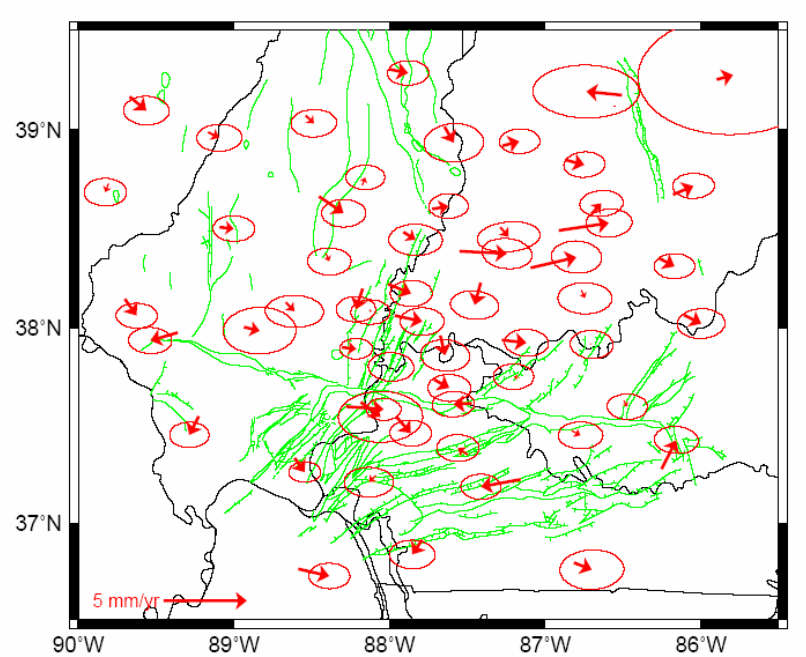

Figure 2. *Preliminary results from the Wabash Valley GPS network, 1997-98. Solid dots indicate locations of GPS sites, as shown in Table 1 and Figure 2. Vector arrows indicate velocities of relative motion of benchmarks with respect to the base station, BLO1, which was occupied continuously during both campaigns. Ellipses show estimated errors in velocity determinations at the 95% confidence level.*

Our preliminary results, based on a one-year measurement interval, from 1997-98, were reported by *Hamburger et al.* [2002]. They indicated statistically significant horizontal motions at 28 of the sites surrounding the Wabash Valley seismic zone. The inferred velocities are highly variable, presumably influenced by systematic and random geodetic errors, as well as significant non-tectonic deformation sources, such as mine- and solution-related subsidence. Nonetheless, the individual site velocities, as well as a formal inversion for tectonic strain, suggest a systematic pattern of shear strain that may be interpreted either as sinistral shear along the NNE-trending Wabash Valley Fault System or as dextral shear along the NE-trending Commerce Geophysical Lineament. While most of our strain estimates remain statistically indistinguishable from zero, the averaged shear strain for the entire network is estimated at $12.7 \pm 6.0 \times 10^{-9}$ yr^{-1}. The shear strain rate estimated for the area surrounding the Wabash Valley Fault System is estimated at $3.6 \pm 4.8 \times 10^{-9}$ yr^{-1}, in a similar direction, but at a significantly smaller magnitude than previously measured rates in the New Madrid seismic zone. Additional observations conducted in 2000, 2002, and 2003 were used to improve measurement precision and to extend the observational base. We have also revised the entire suite of GPS position measurements using the GIPSY-OASIS GPS analysis software. Results are compatible with those reported above, with a downwardly revised strain estimate of $1.8 \pm 1.2 \times 10^{-9}$ yr^{-1} (max. compressional strain, oriented 128.2° ± 10.4°). Strain estimates from the Shawnee network are compatible, but still within the margin of their larger error estimates. The maximum compressional strain is estimated at $17.5 \pm 16.7 \times 10^{-9}$ yr^{-1}, oriented 96.8° ± 21.2°.

Table 1. Tensor Strain and Rotation Rates in the southern Illinois Basin

Subregion[a]	Number of sites	$\dot{\varepsilon}_1^b$ $nstrain/yr$	$\dot{\varepsilon}_2^b$ $nstrain/yr$	Azimuth[c] deg	$(\dot{\varepsilon}_2 - \dot{\varepsilon}_1)/2$ $nstrain/yr$	$\dot{\omega}$ $nrad/yr$	$\Delta = (\dot{\varepsilon}_1 + \dot{\varepsilon}_2)$ $nstrain/yr$	Reduced χ^2
Entire network	74	-1.7±1.2	2.8±1.0	130.6±9.4	2.3±0.8	-0.9±0.8	1.0±1.5	1.31
Shawnee network	22	-26.9±26.1	4.9±8.9	107.2±26.3	15.9±14.8	7.2±12.4	-22.0±25.4	1.00
South WVSZ	20	-2.9±3.9	1.9±2.1	105.1±27.7	2.4±2.3	-0.1±2.1	-1.0±4.2	1.47
North WVSZ	7	-15.4±7.0	1.4±5.3	56.8±14.1	8.4±4.7	-10.8±4.7	-14.0±7.9	1.09
West WVSZ	10	-6.0±3.5	5.3±2.4	122.1±10.6	5.6±2.4	3.0±2.3	-0.7±3.7	0.91
East WVSZ	11	-1.4±2.0	18.4±5.7	173.3±6.4	9.9±2.9	-4.1±2.3	16.9±6.2	1.74
Big Shawnee	24	-27.4±14.2	5.1±4.5	107.0±13.9	16.3±8.0	7.6±6.5	-22.3±13.8	0.95

The Wabash Valley GPS network is expected to provide an important resource for crustal deformation studies in the U.S. midcontinent. It will provide a baseline against which future geodetic measurements may be compared. The next remeasurement of the network, planned for summer 2002, is expected to provide a test of these first estimates of present-day strain across the southern portion of the Illinois Basin, and densification of this regional network is planned for areas of possible high strain accumulation. All data collected as part of this experiment have been archived at the UNAVCO GPS data archive, and will be made available for collaborative regional studies of crustal deformation. Data can be accessed via the internet from http://www.unavco.ucar.edu/data/.

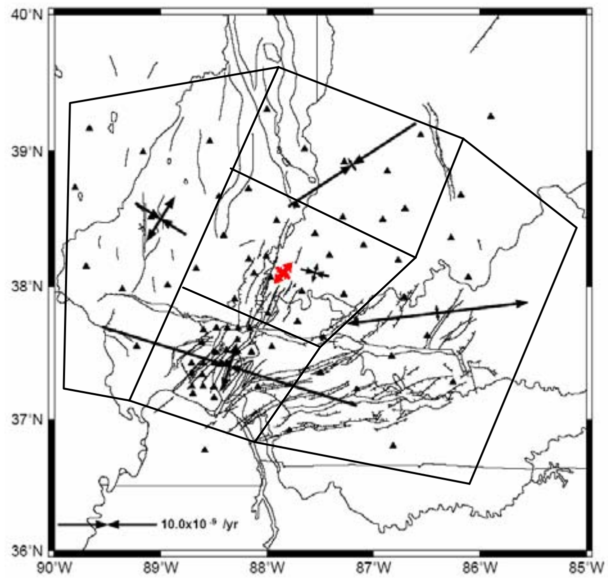

Figure 3. *Inverted strain field, based on observed velocities from Figure 3. Estimated strains are summarized in Table 2. Solid symbols represent orientations and magnitudes of principal strain components for each grid area. Large strain rates in southeastern portion of study area (grid cells 3 and 6) result from poor sampling along the periphery of the network. Open symbols represent the average principal strain rates for the entire study area, assuming uniform strain.*

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